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DISCOVERY

Economic and environmental impact assessment of rainwater harvesting system for a small scale residential area in a typical rural setting

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ABSTRACT

Rainwater has become an important water source in the face of climate change; it is an important water source in many areas with significant rainfall that lack any conventional, centralized supply system. Considering several socio-economic and environmental advantages of reduced cost in mains top and reduced runoff, this study investigated the economics and environmental impact assessment of rainwater harvesting systems (RWHS) on a small-scale residential area in a typical rural setting. Sample survey, onsite observation and analytical approach were applied in the investigation. The economic analysis was done for 1 m^3, 0.75 m^3 and 0.5 m^3 water capacity tanks at a fixed catchment area of 64 m^3. The result indicates that most of the populace (76%) depends on rainwater as a source of drinking water. Environmental assessment of the RWHS demonstrated that best practices in the management of rainwater harvesting were generally poor, as overhanging trees were observed on some of the rooftops of the RWHS. The scenario of rainwater harvesting potential of facilities shows that rainwater is unavailable in the early and later parts of the year and overflow of water tanks occurs within days 101 to 301, an indicator that tanks were undersized. The economic analysis for the various tank sizes indicates that savings of $5,190.36, $7,361.33 and $8,064.23 were made for the 0.5 m^3, 0.75 m^3 and 1 m^3 tank sizes, respectively.

Keywords: Rainwater harvesting, economic analysis, environmental assessment, water demand, Nigeria

1. INTRODUCTION

Rainwater harvesting (RWH) collects the water produced during rainfall events before it can constitute runoff into a river or stream or soak into the ground and become groundwater. It is an important water source in many areas with significant rainfall that need a conventional, centralized supply system (Abu-Zreig et al., 2019). Most semi-urban and rural areas in developing countries lack a

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central water supply system and therefore depend on RWHS. Rainwater has become an important water source in the face of changes in the climate (Adham et al., 2019; Ezzeldin et al., 2022). The geology of some communities makes it difficult to exploit groundwater since the water sources lie more than a thousand meters deep down the earth's crust. Economic-wise, the cost of groundwater exploration and the capital cost for the installation of RWHS far outweigh the income of modest salary earners and low-income residents. One of the options for domestic water is surface water and this also poses a serious challenge because of the waste of productive time and energy to obtain water from the stream. In addition to the impact of urbanization, population explosion, unregulated waste management, etc. Several surface water sources have been heavily polluted and cannot be relied on as portable water sources. In the face of all these challenges, rainwater remains the most viable option for most rural dwellers in developing countries. It is also a good option for areas needing better quality fresh surface water—residents resort to rainwater harvesting. The experience of most rural communities indicates that rainwater is a convenient water source.

Currently, in most rural areas, there are various rainwater harvesting systems, usually based on individual or community preferences without any scientific basis for adoption; there is a need for environmental and economic assessment based on systematic studies to ascertain the environmental impacts and economic benefits of rainwater system (Sheikh, 2020). Factors such as the type of roof material, rainwater conveyance system, dry period and surrounding environmental conditions influence rainwater quality. The typical roofing materials are metal sheets, ceramic tiles, rock slate and Ferro-cement (Mosley, 2005).

Researchers have reported some types of roof cover that are more likely to cause contamination, include asbestos-cement roofs, which can cause RW storage filters to block, reduce the amount of water collected and potentially pose a health risk; metal roofs (except stainless steel) which can release small amounts of leachates, stain water fixtures, for example, copper roofs may colour water green; bitumen felt or coated roofs which can lead to discolouration and odour problems. Most rough gutters, downspouts, and piping capture leaves, twigs or other large debris, thus contaminating RW conveyed (Anchan and Prasad, 2021; Abu-Zreig et al., 2019; Tengan and Akoto, 2021). Environmental assessment of rainwater harvesting systems is therefore essential to mitigate water contamination. Pollutant additions to roof runoff include organic matter, inert solids, faecal deposits from animals and birds, trace amounts of some metals and even complex organic compounds. The longer the dry period, the greater the probability of a higher pollutant load in the first flush. Both E-coli and Heterotrophic Plate Count (HPC) are observed in the first flush of RW, representing the contamination of the catchment area by human activities (Anim and Han, 2008; Tengan and Akoto, 2021).

Several studies have considered sustainable rainwater management to meet various water demands (Ezzeldin et al., 2022). A study that considers rainwater harvesting and integrates a GIS-based method was used to evaluate the proficiency of RWH to satisfy the demand for outdoor irrigation in Tucson, Arizona (Zhong et al., 2022). Abu-Zreig et al., (2019) analyzed the various factors that impact the usage of rooftop rainwater harvesting, examined the quality of the harvested rainwater and gave estimate on the optimum storage tanks that should be incorporated in the building design in Jordan. Another study investigated the potential of rainwater harvesting to meet the water requirement of maize production in the Lubombo plateau of Tanzania (Sacolo and Mkhandi, 2021). Ojeifo, (2011) assessed RWH facilities in Esanland of Edo state, Nigeria; he examined the structural and environmental aspects of the use of underground storage in the study area. Appropriate storage vessels used for RWH include those made of Ferro-cement, plastic, metal and fibreglass (Mosley, 2005). Pathak and Heijnen, (2011) reported that water storage systems could also impact water quality; they observed that when the cement and Ferro-cement tanks are new, they can increase the alkalinity of the stored water and the calcium content. Contaminants can get into the two systems of storage, which are: Above ground storage system and the underground storage system. Kumar, (2008) observed that underground tanks are prone to water contamination in coastal areas due to fluctuations in the groundwater table and leakage of stored water. Pathak and Heijnen, (2007) posited that one of the routes of contamination is through underground runoff; this is particularly significant for underground water tanks when agricultural and environmental effluents that contain Cryptosporidium, Giardia, Campylobacter and Salmonella species leak into the tanks.

Studies that have considered the impact of the small-scale utility of rainwater are generally scarce; this is more critical for most developing countries since this is the prevalent means of rainwater harvesting (Liu et al., 2022) and there are scarcely any central rainwater supply systems. Despite few of these studies, they seem to concentrate on utilizing rainwater for different purposes, such as afforestation in mine areas (Liu et al., 2022), drinking water production (Alim et al., 2020), there are no studies in the region that considers small-scale rainwater environmental and economic factors to meet the water requirement for livelihood, hence the importance of this study. In addition, several factors that are peculiar to several regions have been identified as critical in the utilization of RWHS; local prevailing climate, cost of installation, availability of labour, r maintenance system etc. (Adham et al., 2019; Busico et al., 2021). Studies that integrate these regional variations is therefore critical in providing vital and reliable economic

assessment. This study evaluated a small-scale, typically practiced rainwater harvesting system that is, therefore, more tailored to produce a reliable result based on regional peculiarities.

There is scarce research work on the economic analysis of RWH systems in developing countries (Caleb et al., 2018); economic analysis of RWHS is critical in the adoption of rainwater harvesting techniques and systems and to ascertain the return on investment (Abas and Mahlia, 2019; Jalili and Kolavani, 2020). Several researchers have conducted studies on the economics of RWHS. The objective of the study was to develop the feasibility of an RWHS that incorporates and adapts the water catchment and treatment facilities for non-potable use in Brazil (Lima et al., 2021); Amos et al., (2018) compared the economics of RWHS between Kenya (a developing country) and Australia (a developed country); the study asserted that the economic variability of RWHS in both countries is mainly dependent on the cost of freshwater (Amos et al., 2018). A study that seeks to transform South Indian University did a feasibility study on the effective utilization of rainwater on the campus; the study integrated the runoff from the storm and did a quantitative and qualitative evaluation; the study reported that accumulating about 1,13,678.9 m^3 of stormwater will sustain the institution (Anchan and Prasad, 2021). On the novelty of this study, despite numerous global studies on RWHS, few or no reports considered the economic impact and environmental evaluation of RWHS in the region. In addition, the study area was selected to reduce runoff volume because of the impact of deep gully erosion in the area that has destroyed houses of the people living near the gully.

This study also looks different in the mitigation approach of using non-structural measures against standalone structural measures currently in place in the study area. It suggests using or combining non-structural measures with structural measures as an effective tool to curb erosion menace. This study aims to evaluate the environmental and economic impact of RWHS in a rural setting, considering the prevalent residential scenario in erosion-prone zones of Oko and Nanka communities in the Orumbah North local government area (LGA) of Nigeria as a case study.

2. MATERIALS AND METHOD

Description of the study area

This study is based on Nanka and Oko communities, two autonomous communities in Orumba North Local Government Area of Anambra state, Nigeria. Figure 1 is the map of Nigeria showing Anambra State. Anambra state lies within longitudes 06o35' and 07o30' East and latitudes 05^{o}40' and 06^{o}45' North. The two communities are in Orumba North LGA of Anambra State of Nigeria. It has an area comprising a vast undulating landscape and alluvial plains. It is one of the major erosion zones in the country. Though there are structural measures to mitigate the area's deep gully erosion, using appropriate RWHS can go a long way to reduce the runoff in the region, hence the need to conduct research on optimizing RWHS in the area. The climatic type is the tropical rainforest, comprising rainy and dry seasons. The rainy season lasts from March to October, while the dry season last from November to February. Peak rainfall occurs from June to July, while the second Peak occurs from September to October. The rains could be mild or torrential and often causes flooding and erosion leading to the formation of gullies.

Imo shale is the dominant geologic formation of the study area. It is predominantly shaley and occupies the stable lowlands east of the Nanka Formation-NAF. The Formation consists of dark grey to blush grey shale, siltstone and mudstone. It does not easily allow for a good groundwater supply regarding depth and accessibility. Groundwater exploration in sufficient quantities and qualities as near as possible is not easily achieved. Most residents in the community resort to RW since the available stream is silted and the path leading to it is tortuous, in addition to their location being far away from most households.

Research Design

The designs for this study are a sample survey, analytical and a case study on the environmental and economic assessment of RWHS. The primary data source for this study includes a self-administered questionnaire and personal observation. A representative sample was surveyed and the sample size was determined following Yaro Yamane's formulae. Household questionnaire survey was conducted and four hundred respondents were randomly selected from the households that constitute the study area; this represents a fair portion of the people's opinions. The existing domestic RWH systems were examined through random sample selection, observation and data collection. To ensure that the needed 400 questionnaires were achieved, 450 questionnaires were distributed to residents of different occupational levels in the study area to identify popular water sources, water handling, storage and the environmental scenario of RWH, maintenance of RWH network, perceived prevalence of water-borne diseases, health status and other related information. In contrast, about 407 questionnaires were retrieved and the extra seven were discarded. As much as possible, the researcher observed the RWHS of residents to make an opinion of what is onsite.

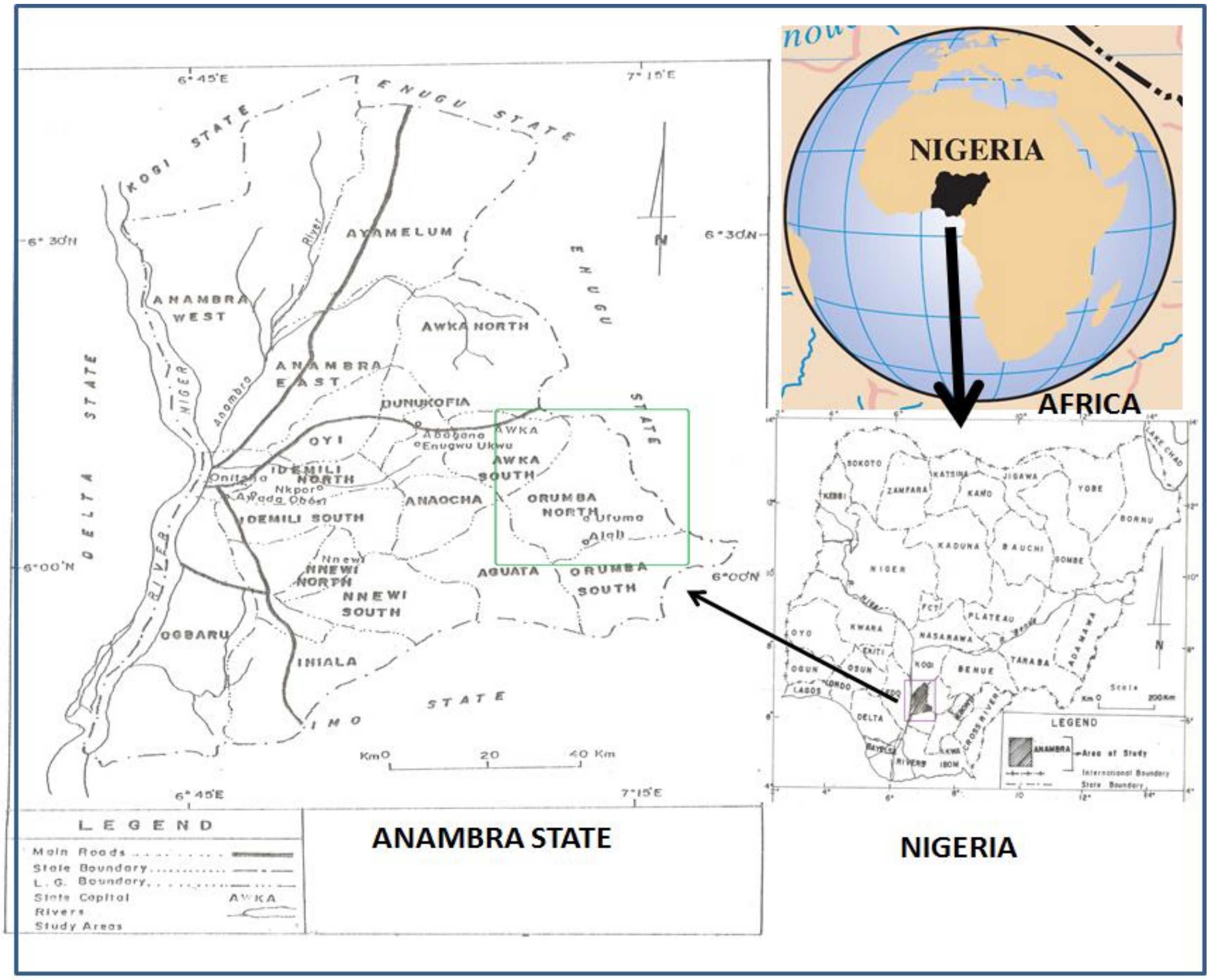

Figure 1 Map of the study area (Orumba North LGA of Anambra State in Nigeria)

Economic Analysis

For the economic analysis, the capital cost for the installation of RWHS was ascertained through a market survey and the operating cost was determined. For a typical rural area, the cost of electricity for pumping the water was excluded. The norm in the area is to install a water tank in the front of the building, while residents use smaller vessels to collect the water manually. In addition, since the RWHS is simple, it is assumed that the family will maintain it at no cost. The mains top-up is idealized as sourcing water from alternative means during a drought or water scarcity. Observation indicates that the majority of the resident depends on water suppliers that fill the same tank used in the rainy season for mains top-up; rainfall is experienced from April to November, while December to March is characterized as a dry season, this means that mains top-up is undertaken for a period of 4 to 5 months depending on rainfall variability.

The mains top-up was included as an operating cost. A discount rate of 10% was assumed for the life span of the RWHS; this was included in the operating cost. Although many residents depend on rainwater solely during the rainy season, a good number of the wealthy populace depend entirely on borehole water throughout the year; the rainfall runoff from these groups could constitute an environmental nuisance, leading to the advancement of the gully erosion in the area. The critical factor in this study's economic analysis is to ascertain the overall savings from integrating rainwater harvesting, which will directly provide economic and environmental benefits. The economics of RWH is a valuable tool; for this study, Net Present Value economic indices were used to analyze the economic benefits of integrating the RWH system. The use of the RWH system that presents several years of economic benefits X is given by:

$$\frac{X_1}{(1+i)} + \frac{X_2}{(1+i)} + \frac{X_3}{(1+i)} + \cdots \frac{X_n}{(1+i)^n} - I = 0 \quad (1)$$

The NPV is used to calculate and compare streams of cash flows that will accrue in the future. It is defined as the difference between the present value of the project future cash inflows and its initial investment. It is given as:

$$\text{NPV} = \sum_{t=1}^{n} \frac{X_t}{(1+i)^t} - I = 0 \quad (2)$$

Where I it the discount rate, I=the cash outflows, n=the number of years.
A project is profitable when NPV is positive.
Plastic tank is prevalent in the region, considering the short lifespan of such material, the number of years for the economic analysis was limited to 10 years.

Data collection and Parameter Estimation

Rainfall data is critical in estimating the reliability and economic returns from adopting RWHS. Twenty (20) monthly rainfall data was used for the modelling (2002-2021); the 20 years of data applied in this study is shown in the appendix. The data was obtained from the Metrological station in the state capital. The above-average data, the average data and the below-average (worst scenario as a result of unreliability of rainfall) were used in the modelling. The runoff coefficient is defined as the ratio between the volume of water drained from the surface and the volume of rainfall. This coefficient is utilized to ascertain the amount of water absorbed by a roof; various values for different roofing materials are ceramic tiles 0.8 to 0.90, corrugated metal tiles 0.8 to 0.9 and enamelled tiles 0.9 to 0.95 (Tomaz, 2010). For the catchment losses, the coefficient of the roof material is critical. The typical roof material in the area is steel roof, with a runoff coefficient of 0.90. The above-average, average and below-average data of the runoff coefficient of 0.9, 0.85 and 0.75 were used, respectively. A typical two-room and parlour apartment that fails within reach of most residents based on socio-economic analysis was used. A catchment area of 64 m2 was used for the analysis. The volume of usable rainwater over time is given as follows:

$$Q_t = C \times A \times P \quad (3)$$

Where Q (t) is the volume of the available water from the RWHS over a given period, A is the roof or catchment area for rainwater collection, P is the rainfall amount (mm), C is the coefficient of the roof material.

The first flush volume was exempted from the analysis since the technology is not prevalent in the area. The above-average, average and below-average data of filter co-efficient of 0.9, 0.85 and 65 was assumed. Typical storage tanks in the area that are affordable for residential uses are 1000, 750 and 500 litres capacity tanks. A plate of 1000 litres (1 m^3) is shown in the appendix. The tank sizes were varied and the economic analysis guiding the decision to purchase the various tank sizes with fixed catchment areas was done for the study. The daily water demand profile for the study area was estimated considering a previous study.

A study by Sydney Water, (2016) obtained its estimates by simply dividing the total water consumption by the population; an estimate of 297 L/person/day was used for the study. 150 L/person/day was assumed for this study considering previous research work (International Reference Centre, 1983; Lima et al., 2021). The above-average, average and below-average data of water demand profiles of 300, 150 and conservative measures of 50 L/person/day, respectively, were used. The 300 L/person/day was based on a previous data estimate (Sydney Water, 2016). Observations indicate that on Saturdays, many house chores are carried out; this includes cloth washing, house cleanup exercise, car washing, etc. The water demand profile of Saturdays was estimated to be 450, 300 and 100 L/person/day, respectively. Table 1 show the parameters used in the modelling. Discount rate of 9% was applied to all future cost PV, total cost of mains top-up of $/$m^3$ 17.40 was assumed based on field survey.

Table 1 Parameters for the RWHS modelling

S/N	Variable Parameters	Above Aver. Value	Average Value	Below Average Value	Fixed Parameters	Value
1	Rainfall profile (mm/yr)	2199	1888	977	Catchment surface area	64 m^3
2	Runoff coefficient	0.9	0.85	0.75	Storage tank volume	0.5, 0.75 and 1 m^3
3	Filter coefficient	0.9	0.85	0.65		
4	Discount rate (%)	0.95	9	7		
5	Mains top-up water cost ($/$m^3$)	22.40	17.40	12.50		
6	Water demand (m^3/yr)	117	62	20		

Data analysis

The data obtained were analyzed with the aid of tables and graphs. Microsoft EXCEL was used for the data analysis. The economic analysis for the RWHS was modeled using Rain Cycle software, version 2.

3. RESULT AND DISCUSSION

The result of the analysis is presented below.

Demographic data

Most of the sampled residents of the study area fall between the ages range 16-44, where 42.75% and 40% represent the active ages of 16-30 and 31-44, respectively. This shows that a high percentage of the residents in the study area are within the active age group. The survey on the occupation of the people indicates that trade/business is the most common occupation with 36.50% and 17.25% represents farmers, apprentices, sales persons, amongst others. Civil servants represent about 16.25%, while the most negligible value of 6.5% belongs to private practitioners. On the number of persons in a household, the 6-9 range gave the highest number with 53.75%; this is followed by 2-4 with 25.25% and the most negligible value of 21% for the ten and above range. A survey on length of stay showed that the majority of the residents have lived for 1-5yrs (30.25%), followed closely by 6-10 (27.50%) and then 16 and above (22.25%), with the most negligible value of 20% for 11-15yrs. It assumes that length of stay is associated with the tendency to install RWHS since residents would not be willing to invest much in the RWH system to relocate after a while.

Potable Water Sources, Management and Environmental Impact

Figure 2 shows the response to potable water sources, water handling and cleanliness of RWH networks and perception of health and water-borne diseases, amongst others. This serves as a pointer to the primary source of water for drinking/domestics, the resident's mode of handling the RWH system that could engender its contamination, the health status of RW consumers concerning WBD and possible sources of the RWH contaminants.

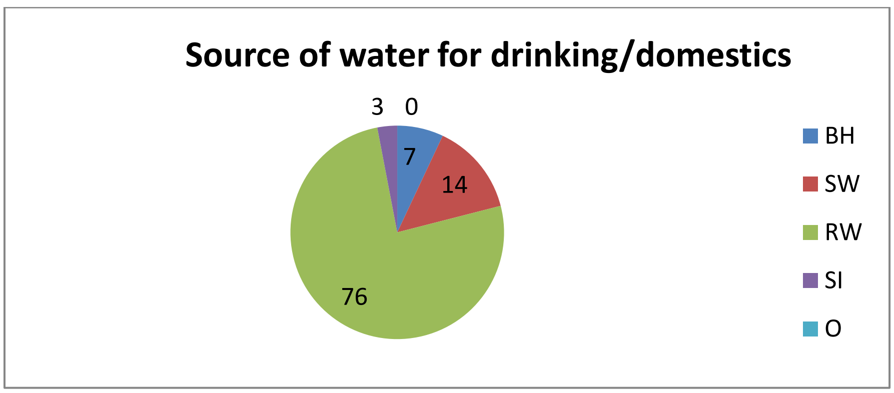

Figure 2 Source of Water for Drinking/Domestics

BH – Borehole, SW- Sachet Water, RW – Rainwater, SI – Stream Water, O - Others

In Figure 2, a total of 76% of the respondents affirmed rainwater as a major source of water for drinking/domestic purposes. 14% of the residents depend on water packaged in transparent plastic bags, referred to as sachet water; this is believed to be more hygienic, though more costly. It is usually produced by companies that deal with drinks. 7% of the residents depend on borehole water and the cost of groundwater exploration in the study area is on the high side, resulting from the area's geological condition. Only 3% depends on the stream; this is understandable since the surface water is far from the residential areas. Only a few indigent populaces will resort to the stress and be strong enough to navigate the rugged terrain.

To ascertain the impact of the environment on the quality of the rainwater harvesting in the study area, survey questions on measures to ensure minimal contaminant were posed to the residents. Figure 3 shows the residents' response to best practices in RW management. The figure indicates that the percentage of respondents who affirmed that the roof opened to the atmosphere, vegetation overhanging the RWHS network and the presence of an inlet filter to storage was generally higher than the non-affirmative responses. Most roofs are open to the atmosphere (88.75%) and hence, to vector animals which can access them. Most of the RWH networks had vegetation over them (60%), which implies that living organisms, dry leaves, debris and dirt can impact the roof and consequently enter storage devices leading to contamination. 72.5% of the respondents had inlet-filter attached to their storage tanks, with 22.5% having none; this shows that people know the need to keep debris from passing into RW storage. Onsite observation during the study period shows the accumulation and clogging of the filter by debris begging to be cleaned. This is in addition to colour change due to rusting of the metallic filter. Diversion of first-flush waters is a feat that only 15% could carry out, whereas a higher percentage of respondents (85%) could not divert first-flush water. To divert first flush water at the beginning of

each rain event requires availability and consistency in keeping the RW storage lid covered or temporarily out-channelling the conveyance system. This means that this 15% may only sometimes be available at the time of a rain event to accomplish this feat consistently. It was observed that this diversion is usually carried out at the beginning of rainy seasons but not at the onset of each rain event; this means that, even after some periods of no rain, residents hardly divert first-flush waters, which may be due to the inconveniences encountered. 37.5% treat their water before use while 62.5% do not; this percentage of people who treat RW before use is on the low side as compared to those who do not; this could be a result of the perception that RW is relatively pure. Amongst the 120 respondents who treated their RW before use, 36 (30%) boiled the water and addition of chemicals with 18 (15%), 42 (35%) filtration, while others (mainly sedimentation) is 20%.

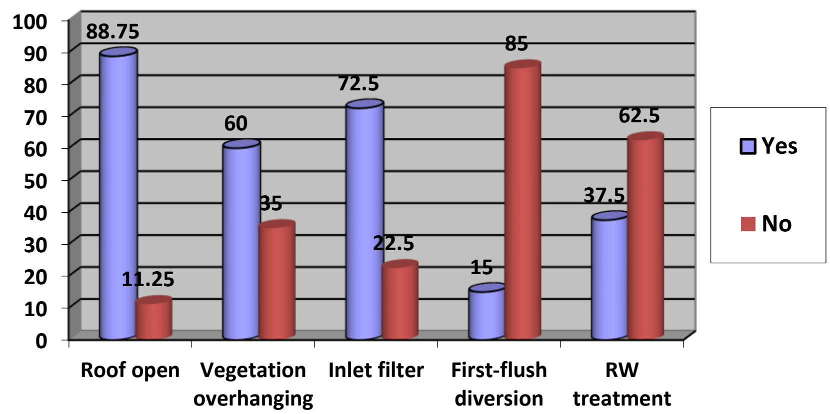

Figure 3 RWHS environmental assessment and management

Washing of RW storage was mainly carried out at the beginning of the rainy season (48.75%), 25% could not remember when theirs was lasted washed (these were mainly concrete storages), 16.25% depended on convenience, while others (10%) such as bi-monthly/periodical washing or whenever the storage is empty. In the treatment method of RW before potable use, the majority applied filtration (35%), followed by boiling (30%), others such as sedimentation 20%, while the most petite application was chemical (15%). Generally, people made some effort to treat the RW before use.

Environmental scenario and impact on Health Status

Figure 4 shows the health status of the residents, this could be connected to the poor environmental conditions of RWHS and management.

Four primary water-related diseases identified in the area were assessed. Figure 4 shows the percentage of residents who suffered one water-borne disease (WBD) or another, while Figure 5 gives an overview of the percentage responses on health regarding WBD.

The affirmatives for general symptoms of WBD are higher (77.5%) than non-affirmatives put together (22.5%). 87.5% (280 persons) had suffered from any WBD listed; 12.5% were negative, while 10% were indifferent. While 45% knew persons who had suffered a WBD in the past 12 months, 35% were non-affirmative and 20% did not know. WBD is common and was attested to by 57.5%; 22.5% answer in the negative, while 20% did not know where to fall in. The same percentages as above were noted for the high incidence of WBD in the rainy season. 60% affirmatives and 20% non-affirmatives were recorded for general health deterioration during rainy seasons.

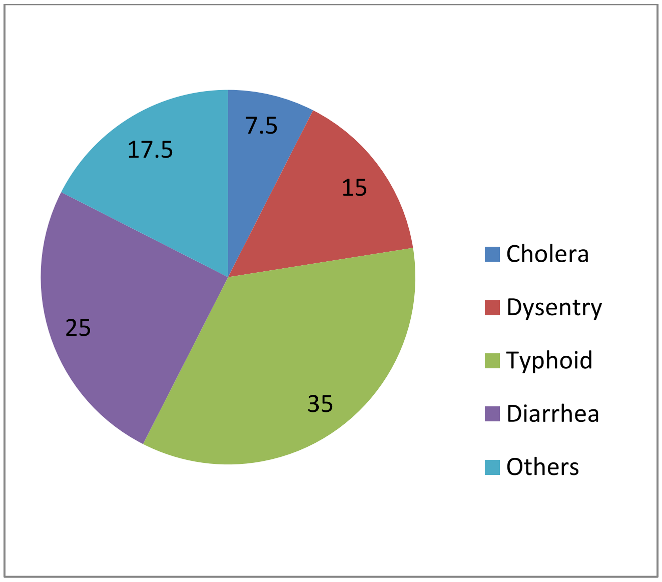

Figure 4 Water-borne Diseases Suffered

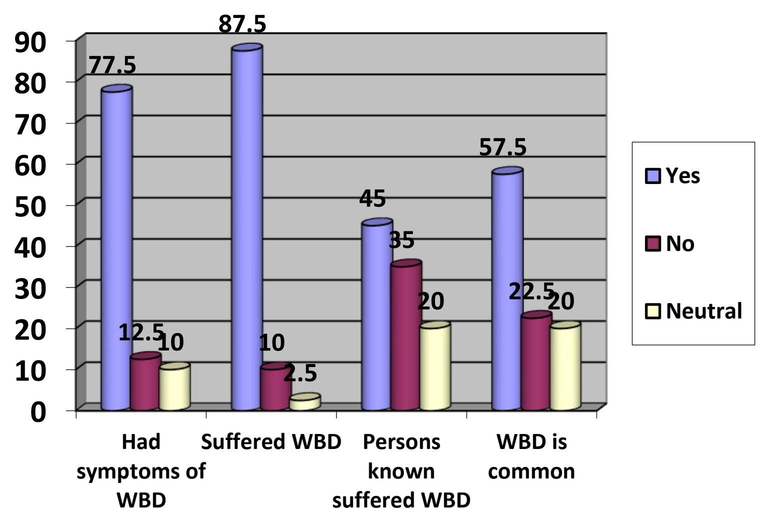

Figure 5 Percent Responses on Perception of WBD by Respondents

Figure 5 gives a chart of respondents' percentage responses on their perception of WBD. It is seen that a high percentage of the respondents have had something to do with WBD and are aware of their existence. The ones who ticked neutral options could mean that they may or may not have experience those symptoms but cannot remember or are unwilling to divulge such information. To ascertain the relationship between the usage of RW and health status of the residents, cumulative data of records from hospitals were used. A significant correlation coefficient between variables shows a common origin and pathway (Oguntoke et al., 2009). Hence, the significant correlation coefficient between various WBD reports obtained from the hospital records indicates that the diseases have a common origin, which can be referred to as the usage of RW.

Rainwater Harvesting Scenario and Economic analysis system

An appraisal of the rainwater savings is critical in the adoption of the system; the tank size has been attributed to be a major factor that has both environmental and economic advantages. Figure 6 shows the data on total input of rainwater to the tank. The figure indicates that less than 0.1 m^3/day of rainwater has harvested from day 1 to 51 and day 301 to 365 during the entire 20 years

precipitation data. This necessitates the dependence on mains top-up for the period of drought or dry season. However, a tank design that considers the consumption rate of households will be a vital tool to develop tank size that will provide adequate water for the dry/drought season; this will definitely require a big storage tank and will incur more cost.

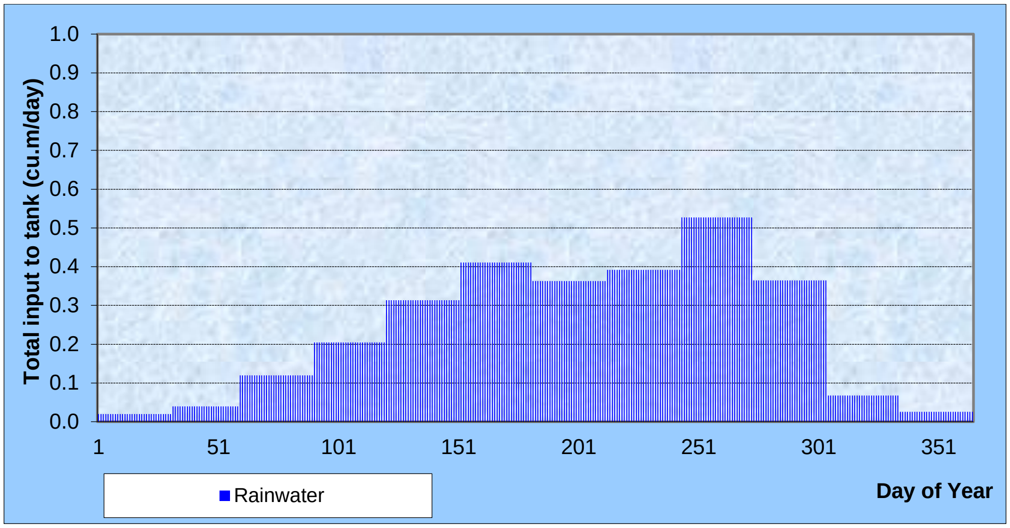

Figure 6 Total input of RW to tank over the year

The figure also indicates that input of 0.5 m^3/day is obtained around day 251; generally, there was a gradual increase in the rainwater input to the tank and a decline towards the end of the year. This trend is critical in the planning and deployment of RWHS for residents. For instance, a study on the possibility of rainwater to meet outdoor irrigation requirements reported that about 32% of the city of Tucson, in Arizona, can be satisfied by rainwater for more than eight months of the year (Zhong et al., 2022). It is, therefore, critical to ascertain the potential of rainwater to meet water demands, as done in this study. Figure 7 shows the overflow from the tank; this is a critical tool in harnessing runoff to avert flood; this is critical for the study area since the area is an erosion-prone zone. The overflow was recorded from day 101 to day 301; this shows that an increase in tank size is essential to avert flood in the region, though this may have a cost implication for the residents.

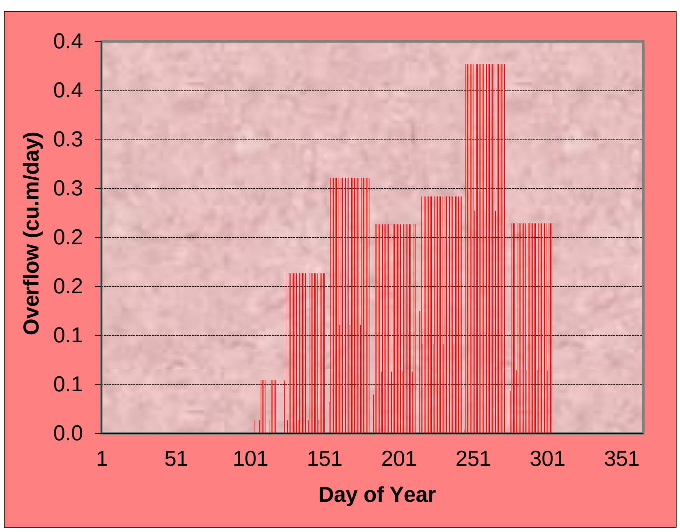

Figure 7 Overflow from the tank

The maximum overflow occurs between days 251 to 275, with about 0.4 m^3/day released as runoff, constituting an environmental nuisance. Since the government has spent considerable funds on the structural remedy for the deep gully erosion in the region, the government should consider optimization of RWHS as a remedy or in combination with the structural efforts. Hence, it is suggested that the government should subsidize the cost of tanks through installation and provision of expert advice in the design and installation of RWHS as a non-structural remedy to mitigate the menace of erosion in the study area. The water

source during the year is critical to understand the economic advantage of rainwater; generally, the residents' mains top-up is from water suppliers that sell water to residents using tankers. Others resort to buying water from a few residents that can afford to drill a borehole. Figure 8 shows the source of water supplied to the end users in this scenario. The figure indicates that the water demand for a typical household in the study area could be satisfied through rainwater.

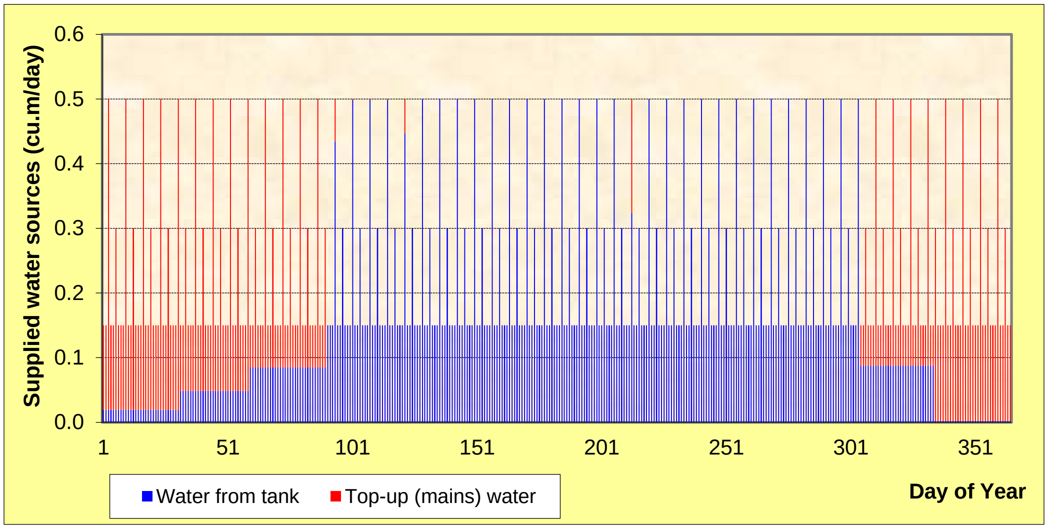

Figure 8 Sources of water supplied to end-users

Studies have shown that 46% of people do not utilize rainwater because of the cost of storage tanks, while 80% choose tanks without proper guidance (Abu-Zreig et al., 2019). There is a need to conduct studies to guide the economic suitability of rainwater tanks. Table 2 shows the result of the economic evaluation of the 1 m^3 capacity tank for rainwater storage; generally, the cost of the tank increases with size in the market. The capital cost for the 1 m^3 capacity tank is $315 from the market survey and observation. The capital cost includes the cost of the tank, the transportation and cost of the conveyance system; this includes the gutter, funnel and filter. The table shows the economic analysis for ten years. The table shows that for the first year, the capital cost and the cost of mains top-up ($578.65) have an annual value of $ 893.65. The NPV of the mains top-up decreased from $578.65 in the first year to $530.87 in the second year.

Table 2 Economic analysis of RWHS based on NPV for the 1 m^3 capacity tank

	Breakdown of RWHS cost at NPV				Mains only cost		Savings @ PV
Capital Cost ($)	Year	Mains Top-up Cost	Yearly total Present Value ($)	Cumulative NPV ($)	Year Total PV ($)	Cumulative NPV ($)	Savings @ PV
315	1.00	578.65	893.65	893.65	1,776.50	1,776.50	882.85
	2.00	530.87	530.87	1,424.53	1,629.82	3,406.32	1,981.79
	3.00	487.04	487.04	1,911.57	1,495.24	4,901.56	2,989.99
	4.00	446.83	446.83	2,358.40	1,371.78	6,273.34	3,914.95
	5.00	409.93	409.93	2,768.33	1,258.52	7,531.86	4,763.53
	6.00	376.08	376.08	3,144.41	1,154.60	8,686.47	5,542.05
	7.00	345.03	345.03	3,489.45	1,059.27	9,745.73	6,256.29
	8.00	316.54	316.54	3,805.99	971.81	10,717.54	6,911.55
	9.00	290.41	290.41	4,096.40	891.57	11,609.11	7,512.71
	10.00	266.43	266.43	4,362.82	817.95	12,427.06	8,064.23
	Total	4,047.82		4,362.82		12,427.06	8,064.23

The NPV for the 9th and tenth years was $290.41 and $266.43, respectively. The total value of the breakdown of the RWHS cost at NPV of the mains top-up at the ten-year expiration is $4,047.82. The economic analysis also considered a situation where the residents depend solely on alternative water sources, assuming that a 12 months drought was experienced. The main top-up cost

for the first year will be $1,776.50; this will imply enormous costs and would be difficult for the residents to survive. The last column of the table shows the savings accrued to the residents as a result of installing RWHS; for the first year, $882.85 expenditure was avoided, while a cumulative saving of about $ 8,064.23 was saved for ten years.

Table 3 shows the result of the economic evaluation of the 0.75 m^3 capacity tank for rainwater storage. The capital cost for the 0.75 m^3 capacity tank is $272 compared to the tank's capacity. The main top-up cost considering utilizing RW for the first year is $311.42; the cost declined yearly to $288.58 in the tenth year. The annual cost of the mains top-up is $2,998.72. The cumulative value of utilizing the main top-up and rainwater for ten years is $3,118.72. Table 3 shows the result of the economic evaluation of the 0.75 m^3 capacity tank for the rainwater storage system.

Table 3 Economic analysis of RWHS based on NPV for the 0.75 m^3 capacity tank

	Breakdown of RWHS cost at NPV				Mains only cost		Savings @ PV
Capital Cost ($)	Year	Mains top-up costs ($)	Yearly total Present Value ($)	Cumulative NPV ($)	Yearly Total PV ($)	Cumulative NPV ($)	RWHS Cum. Yearly savings
272	1.00	311.42	431.42	431.42	1,088.37	1,088.37	656.95
	2.00	308.80	308.80	740.22	1,079.20	2,167.57	1,427.35
	3.00	306.19	306.19	1,046.41	1,070.10	3,237.67	2,191.25
	4.00	303.61	303.61	1,350.03	1,061.08	4,298.75	2,948.72
	5.00	301.05	301.05	1,651.08	1,052.14	5,350.89	3,699.81
	6.00	298.52	298.52	1,949.60	1,043.27	6,394.16	4,444.56
	7.00	296.00	296.00	2,245.60	1,034.48	7,428.64	5,183.04
	8.00	293.51	293.51	2,539.11	1,025.76	8,454.40	5,915.29
	9.00	291.03	291.03	2,830.14	1,017.11	9,471.51	6,641.37
	10.00	288.58	288.58	3,118.72	1,008.54	10,480.05	7,361.33
	Total	2,998.72		3,118.72		10,480.05	7,361.33

The cost is less; compared to the 1 m^3 capacity tank for rainwater storage, which has a cumulative value of $4,362.82; this indicates that generally, the mains top-up and rainwater harvesting cost increases with tank size. The cumulative NPV of the mains top-up only indicates that depending solely on water suppliers for the study area will cost $1,088.37, $2,167.57 and $3,237.67 for the first, second and third years, respectively. While the eighth, ninth and tenth will cost $8,454.40, $9,471.51 and $10,480.05, respectively. This study shows that rainwater is a money-saving system for the residents that depend on it.

A comparative analysis of the savings from the 1 m^3 and 0.75 m^3 capacity tanks for rainwater storage indicates that whereas $7,361.33 is the cumulative savings from the 0.75 m^3, the 1 m^3 capacity tank has a comparatively higher value of $8,064.23. It is be deduced that the bigger the storage device, the better the savings for the residents. Table 4 shows the result of the economic evaluation of the 0.5 m^3 capacity tanks for rainwater storage; the capital cost for the 0.5 m^3 capacity tank is $ 120. The table shows that for the first year, the capital cost and the cost of mains top-up is $272.49, which has an annual value of $579.50. The NPV of the mains top-up decreased from $275.49 in the first year to $252.51 in the tenth year. The yearly NPV ranged between the values of $141.58 to $579.50 within ten years. On the cumulative NPV, the value increased from $579.50 in the first year to $2,423.06 in the tenth year.

Table 4 Economic analysis of RWHS based on NPV for the 0.5 m^3 capacity tank

	Breakdown of RWHS cost at NPV				Mains only cost		
Capital Cost ($)	Year	Mains top-up costs ($)	Yearly total Present Value ($)	Cumulative NPV ($)	Year Total PV ($)	Cumulative NPV ($)	Savings @ PV
120	1.00	272.49	579.50	579.50	1,088.37	1,088.37	508.87
	2.00	270.2	282.11	861.62	998.50	2,086.87	1,225.26
	3.00	267.92	258.82	1,120.43	916.06	3,002.93	1,882.50
	4.00	265.66	237.45	1,357.88	840.42	3,843.36	2,485.47

	5.00	263.42	217.84	1,575.73	771.03	4,614.38	3,038.66
	6.00	261.20	199.86	1,775.58	707.37	5,321.75	3,546.17
	7.00	259	183.35	1,958.94	648.96	5,970.71	4,011.77
	8.00	256.82	168.21	2,127.15	595.38	6,566.08	4,438.93
	9.00	254.65	154.33	2,281.48	546.22	7,112.30	4,830.83
	10.00	252.51	141.58	2,423.06	501.12	7,613.42	5,190.36
	Total	2623.87		2,423.06		7,613.42	5,190.36

The savings from using RWHS in the first year from the economic assessment indicates that $508.87 was saved using the PV estimation. The savings more than doubled in the second year to $1,225.26 and increased to $4,830.83 in the ninth year, with a cumulative ten-year savings of $5,190.36. A comparative analysis of the tank sizes indicates that savings of $5,190.36, $7,361.33 and $8,064.23 were made for the 0.5 m^3, 0.75 m^3 and 1 m^3 tank sizes, respectively. The trend indicates that more savings are made when the tank capacity increases; it is suggested that two or more tanks can be combined to have more savings from the rainwater harvested; this will add both economic gains and environmental benefits of reduced runoff volume. Residents should endeavor to purchase storage tanks with higher capacity, despite the high initial capital cost. This study aligns with previous studies that reported that RW harvesting is viable (Stec and Zelenakova, 2019). Therefore, this study affirms that small-scale RWHS is viable. However, this may be attributed to the long duration of the rainfall and the fact that pumping and maintenance costs were exempted from the economic analysis.

4. CONCLUSION

Economic analysis of RWHS is critical in adopting suitable rainwater harvesting techniques and systems and ascertaining the return on investment. This study investigated the economics and environmental impact assessment of rainwater harvesting systems in a small-scale residential area in a typical rural setting. The study is based on Nanka and Oko communities, two autonomous communities in Orumba North Local Government Area of Anambra state, Nigeria. The sample survey was taken from the study area and onsite observation and NPV economic indicators were used to ascertain the cost-to-benefit ratio of 1 m^3, 0.75 m^3 and 0.5 m^3 water capacity tanks at a fixed catchment area of 64 m^3. The survey result indicates that most people in the study area depend on rainwater as a source of drinking water. An environmental assessment of the RWHS established that the management of rainwater harvesting facilities was generally poor. On assessing the total input to the tank, the study noted that about 0.5 m^3/day of maximum water input is made around day 251. The scenario of rainwater harvesting potential of facilities shows that the tanks are empty in the early and later parts of the year and overflow of water tanks occurs within days 101 to 301, an indicator that tanks were undersized. On the economic analysis, a cumulative saving of about $ 8,064.23 was made for the 1 m^3 tank size. A cumulative saving of $5,190.36 and $7,361.33 was made using the 0.5 m^3 and 0.75 m^3 tank sizes over ten years, respectively.

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Author contribution statement
This work was carried out in collaboration between all authors. Authors Emmanuel Chibundo Chukwuma designed the study, Joy Nkechi Chukwuma and Emmanuel Chibundo Chukwuma carried out the field survey and collected the data, Emmanuel Chibundo Chukwuma, Jeremiah L Chukwuneke and Joseph I Ubah analyzed the data, wrote the protocol, Emmanuel Chibundo Chukwuma wrote the first draft of the manuscript, all the authors joined to edit and approve the manuscript.

Informed consent
Not applicable.

Ethical approval
Not applicable.

Conflicts of interests

The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

Appendix

Table 1 20 years rainfall data used for the modelling

Yr\Mnths	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	(mm/yr)
Year 1	4.8	52.2	87.5	235	276.5	248.8	301.3	310.2	366.9	264	25.9	7.8	2180.9
Year 2	13.1	29.6	56.9	143.5	200.2	266.4	294.1	217.3	293.4	354.8	56.8	1.4	1927.5
Year 3	2.3	1.5	38.5	113.4	252.5	238.3	332.8	310.9	377.4	208.9	14.5	4.2	1895.2
Year 4	64	34	90	116.8	209	255	308	272	323	222	51	7.5	1952.3
Year 5	1.2	34	90	150	209	255	308	272	326	222	51	17	1935.2
Year 6	64	34	90	116.8	209	255	308	272	323	222	51	7.5	1952.3
Year 7	14	13.4	90	150	253.9	217.7	308	272	323	214.5	93.9	39.9	1990.3
Year 8	8	33.3	123.4	150	209	234.4	57.9	290.7	323	222	51	17	1719.7
Year 9	14	47.8	127.8	125.1	209	255	308	272	566.5	208.1	51	17	2201.3
Year 10	14	34	34.7	150	209	255	170.7	272	323	222	51	17	1752.4
Year 11	14	15	69.8	102.4	243.5	251.7	547.8	300.9	350.3	304.2	43.8	60.5	2303.9
Year 12	0	34	90	150	278.5	313.2	186.9	274.5	264.3	349.9	26.7	0	1968
Year 13	0	42.4	36.6	117.7	189.9	228	266.6	272	349.6	259.3	126.6	14.5	1903.2
Year 14	0	56.5	11.9	67.9	202.6	174.7	226.3	256.2	339.5	222	51	17	1625.6
Year 15	14	0	0	150	209	369.9	118.4	165.5	327.8	318.3	36.7	17	1726.6
Year 16	14	0	52.9	128	71.2	280.2	141.2	227.2	280	139	0	41.4	1375.1
Year 17	0	5.1	41.7	240.4	220.8	218.1	161.1	272.5	430.5	199.3	0	22.4	1811.9
Year 18	2.2	15.1	129.4	36.9	191.6	366.3	121.3	275.8	240.8	219.8	41.5	17	1657.7
Year 19	0	0	276.5	150	205.4	346.1	176.1	315.2	444.3	295.9	0	2.5	2212
Year 20	13	24.3	72.9	163.1	219.8	283.3	284.7	176.1	291.6	236.9	40.4	8.5	1814.6

Plate 1 Typical plastic rainwater storage tank use by residents

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